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# MEASURING THE PLASTIC RESPONSE IN POLYCRSYTALLINE MATERIALS USING IN-SITU X-RAY DIFFRACTION

J. Hawreliak, M. Butterfield, B. El-Dasher, J. McNaney, H. Lorenzana

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# MEASURING THE PLASTIC RESPONSE IN POLYCRSYTALLINE MATERIALS USING IN-SITU X-RAY DIFFRACTION

**James Hawreliak*, Martin Butterfield, Bassem El-Dasher, James McNaney, Hector Lorenzana**

***Lawrenence Livermore National Laboratory, P.O. Box 808, L-367, Livermore, CA, 94550 , *hawreliak1@llnl.gov,**

**ABSTRACT :** The insight provided by ultra-fast lattice level measurements during high strain rate high pressure experiments is key to understanding kinetic material properties like plasticity. In-situ x-ray diffraction provides a diagnostic technique which can be used to study the governing physical phenomena of plasticity at the relevant time and spatial scale. Here we discuss the recent development of a geometry capable of investigating plasticity in polycrystalline foils. We also present some preliminary data of investigations into shock compressed rolled copper foils.

**INTRODUCTION:** In shock loading experiments, where the compression is typically uni-axial, a large sheer stress is generated leading to plasticity which is governed by the generation and motion of dislocations [Meyers 1994]. In the shock processes the atoms are uni-axially, pushed closer together along the compression direction. The lattice level result is the diffraction planes with normal components along the shock direction become compressed. The dislocations compress the lattice in a direction lateral to the compressive force, resulting in compression of the lattice planes parallel to the shock and relaxation of the components normal to the shock direction. It is critical to measure material properties in-situ and single shot as plastic behavior is irreversible and the material response is dependant on the loading pathway [Preston *et al.* 2002]. X-ray diffraction offers the ability to measure the changes in the crystallographic plane spacing. The lattice level response offers insight into bulk material properties like strength which ultimately keep the material from achieving a state of perfect hydrostatic compression[Singh 1993]. For a better understanding of governing physical phenomena which determine material response and to build predictive materials models to address conditions in extreme environments lattice level measurements that can be provided by x-ray diffraction are essential. Here we outline a technique that can be used to diagnose the lattice level response in shocked polycrystalline materials.

**PROCEDURES, RESTULTS AND DISCUSSION:** In-situ x-ray diffraction can measure the change in lattice plane spacing due to shock compression. We have designed a cylindrical polycrystalline pinhole camera (CPPC) geometry to investigate the lattice level response of shock polycrystalline materials [Hawreliak *et al.* 2007]. In this geometry diffraction from crystallographic planes forms circles on the inside of the cylindrical detector, see Fig. 1. As a function of the azimuthal angle $\phi$ around the inside of the detector the orientation of the plane relative to the compression direction is given

by $\cos\alpha = \cos\theta\cos\phi\sin i - \sin\theta\cos i$, where $\alpha$ is the angle relative to the compression direction, $\theta$ is the Bragg angle, and $i$ is the angle of the sample relative to the axis of the camera. Using this relation when the image plate is unrolled we observe compression associated with the diffraction plane varying across the image plate. In the example shown in Fig 1, when the detector is laid flat the lattice planes with there normal parallel to the compression direction would compress and shift more due to the increase compression then those with their planes parallel to the compression direction. The difference in compression can give us a measure of the plastic response.

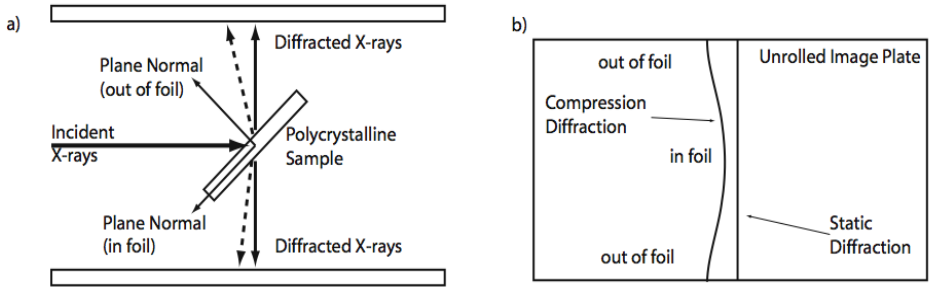


**Figure 1:** A schematic diagram of the CPPC and the image plate. a) shows the diffraction from a single plane in a polycrystalline foil. While two vertical diffraction vectors are shown, one is sensitive to the compression direction, the other is sensitive to the lateral direction which is determined by the plane normal . b) is how the measured compression varies as azimuthal angle on the unrolled detector where in foil and out of foil are in reference to a).

Example data from rolled copper foils, 25 microns thick, shocked loaded with a laser drive to 50 GPa we can see the raw data shown in Fig 2a). The data shows diffraction from (111), (200), (220), (311), and (222) where the static and compressed diffraction signals are labeled. By looking at the compression of the [111] plane as a function of cos$\alpha$, we can look at the degree of plastic relaxation. Due to the experimental geometry to allow the drive beams, there were no measurements of compression made along the shock direction in the foil. Using the experimental data and a least squares fit we can estimate the compression. From this we observe that copper on a nano-second timescale is hydrostatically compressed ( within the uncertainty of the measurement).

While the current set of nanosecond experiments do not have the temporal resolution to determine a timescale for lattice relaxation, which for single crystals has been estimated to be at the pico-seconds [Bringa *et al.* 2006], in principle with the development of forth generation short pulse ultra-bright x-ray sources it will be possible to study these timescale. Also, the instrument does not have sufficient resolution to determine strength in the copper foil, it can provide an upper bound on the strength based on the elastic constants, and shows for the first time that the plastically compressed state in copper is nearly hydrostatically compressed. This technique currently employed on laser based systems, can provide much needed insight into material response at high pressures.

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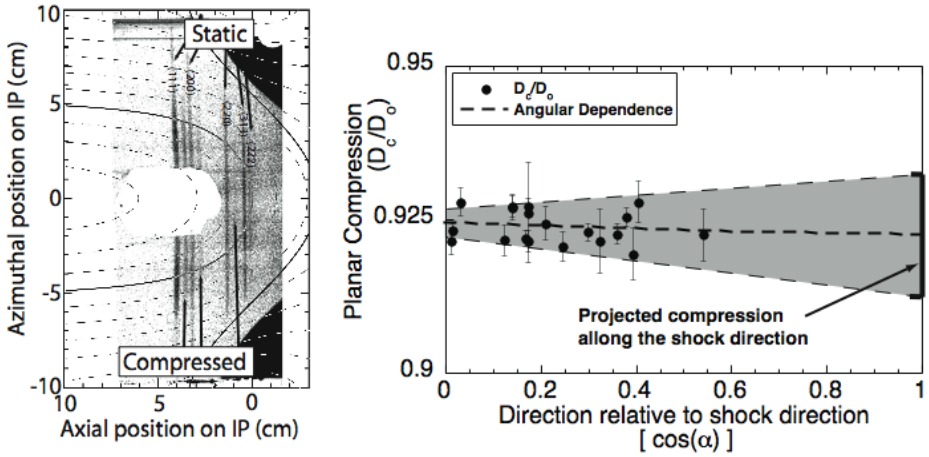


**Figure 2**: a) an example of raw experimental data with the plane orientations relative to the compression direction overlaid and b) the plot of the compression of the 111 plane as a function of angle relative to the compression direction, because there were no measurements made along the shock direction the measured data is extrapolated to the axis, the error is based on a least squares fit to the data.

**REFERENCES:**

Bringa, E. M., K. Rosolankova, R. E. Rubb, B. A. Remington, J. S. Wark, M. Duchaineau, H. K. Daniel, J. Hawreliak and J. Belak (2006). "Shock deformation of face-centred cubic metals on subnanosecond timescales." Nature Materials **5**: 805-809.

Hawreliak, J., H. E. Lorenzana, B. A. Remington, S. Lukezic and J. S. Wark (2007). "Nanosecond x-Ray diffraction from polycrystalline and amorphous materials in a pinhole camera geometry suitable for laser shock compression experiments." Review of Scientific Instruments **78**(8): 083908-6.

Meyers, M. A. (1994). Dynamic Behavior of Materials, Wiley-IEEE.

Preston, D. L., D. L. Tonks and D. C. Wallace (2002). "Model of plastic deformation for extreme loading conditions." Journal of Applied Physics **93**: 211.

Singh, A. K. (1993). "The lattice strains in a specimen (cubic system) compressed nonhydrostatically in an opposed anvil device." Journal of Applied Physics **73**(9): 4278-4286.